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ABSTRACT

Low cost digital audio recording/play back systems are developed by means of adapter style configuration combined with video tape recorders. The adapter works as a signal converter between audio signals, PCM signals and pseudo-video signals, and thus VTR's can be used without any modifications. Two kinds of systems are developed, for consumer use and for professionsl use. The former is based on home-use VTR's like Betamax, and the latter, on VTR's with performances equal to or better than U - matic systems. Their detailed structure, data configuration, and dropout compensation methods are presented.

1. INTRODUCTION

It is well known that technical limitations of conventional analogue tape recorders can be solved by pulse code modulation techniques. Nevertheless, the most of digital audio recorders previously developed are restricted as experimental or in-house use and the technology has long been considered as too expensive to replace conventional analogue tape recorders.

This paper deals with a new system of digital audio tape recorders that is an adapter combined with a video tape recorder, and is able to break through above cost problems [1],[2],[3]. The adapter works as a signal converter between audio signals, PCM signals and pseudo-video signals. Therefore, video tape recorders can be used without any modifications.

One of the points that makes the system cheaper is the application of low cost cassette-type video tape recorders, which have relatively poor characteristics in dropouts comparing to four head video tape recorders used in previous digital audio machines [4],[5]. In order to solve that, effective methods for dropout compensation are developed.

Fig.1 and 2 show the picture of the systems. PCM-1 (Fig.1) is designed for consumer use and to be used with Beta-max type VTR's. PCM-1600 (Fig.2) is for proffesional use and VTR's must have performances equal to or better than U-matic systems. PCM-1 has been marketed since September 1977, and the first lot of PCM-1600 was installed in April 1978. Both are two channel systems and main specifications are shown in Table 1.

Table 1.Main Specifications

	PCM-1	PCM-1600
1.Number of channels	two	two
2.Modulation system	PCM system using standard NTSC TV signals	
3.Sampling frequency	44.056 kHz	
4. Transmission rate	1.726 Mbits/sec.	3.5795 Mbits/sec
5.Quantization	13 bit compounded 3-polygonal lines	16 bit linear
6.Dynamic range	85 dB	95 dB
7.Harmonic distortion	0.03 %	0.03 %
8.Wow and flutter	Below the bound of measurement	
9.Frequency responce	2Hz-20kHz ± 1dB	20Hz-20kHz $^{+0.5}_{-1.0}$ dB
10. Dropout compensation method	Interleave and CRCC linear interpolation	Error correction by cross word code

2. DROPOUTS ON MAGNETIC TAPES

Dropouts on magnetic tapes are mainly caused by scratches or small dusts which are made or sticked during the process of production or when being used. In order to design dropout compensation systems, statistical data of dropouts must be obtained. Fig.3 shows an example of the distribution of dropout length, while six rolls of tapes are sampled from different production lots, and are measured for one hour. The threshold of dropouts is assumed to be -20dBs and a interval between dropouts shorter than 1/6 of horizontal video line is ignored and the dropout is considered to be continued at that point.

99.9% of dropouts are within three horizontal lines, but even one chance in several hours, of making a noise by dropouts, can not be allowed for high performance digital audio recorders.

Fig.4 shows the variation in dropouts between production lots, that is more than ten times. The dropout compensation system must based on the variation of tape production and shipping test standards.

3. PCM-1, A CONSUMER USE DIGITAL AUDIO UNIT

3.1 Structure

Fig.5 shows a block diagram of the PCM-1. The structure is completely separated into two sections, recording (upper part) and play back (lower part). Each main block is explained below.

[A/D block] A twelve bit linear A/D converter is time-shared by left and right signal channels. In addition to that, one bit is used to control gain switchable amplifier (1:4). The bit works as an exponent, and in total, thirteen bit compounded quantization with three polygonal lines is carried out.

[Memory block in recording section] Static RAM of 8K bits is used for the purpose of interleaving the data as well as time base compression for inter-data gap at vertical synchronizing pulses. Cyclic redundancy check code is added after the memory block.

[Memory block in play back section] The signal is sent into memory block after checking CRC code. The memory is consist of 16K bit static RAM and works as de-interleaver, time base expansion for inter-data gap, and time base correction for jitter compensation.

[D/A block] Similar to A/D block, a twelve bit linear D/A converter is time shared, and a gain switchable amplifier is used for nonlinear decoding. Analogue circuit of linear interpolation is added for dropout compensation.

3.2 Data Configuration

Fig.6 (a),(b) show the data configuration on a horizontal line and even/odd field line of pseudo-video signals, where letters L and R mean 13 bit information data for left and right channel respectively, and subscript represents its data sequence. Odd numbers of data are not shown in Fig.6(a). They are put in another horizontal line, by interleaving. CRC means 16 bit cyclic redundancy check code. Inter-data gap shown in Fig.6(b) is 17.5 horizontal lines in average, which is necessary for vertical synchronization, head switching and to put in data control signals such as automatic detection of emphasis or address code for editing.

3.3 Dropout Compensation Method

Fig.7 shows the interleave system of PCM-1, where numbers in the frame represent the sequence of 26 bit word which includes both channels. One field consists of eight interleave blocks. The first to the seventh interleave block include 92 words, while the 8th, 91 words. The interleave is carried out by sending even and odd number separately.

CRCC is added in each horizontal line to detect dropouts. Consequently, a dropout within 46 words (or 15 horizontal lines) can be compensated by linear interpolation method, while any other error is not permitted in the corresponding "better half" words.

3.4 Characteristics

Several characteristics of PCM-1 are shown below, comparing with high performance analogue tape recorder with two tracks and 15 inches/sec. speed. Fig. 8 compares the frequency responce and the dynamic range of PCM system with that of a conventional tape recorder. The characteristics of the PCM system do not depend more or less on frequency or on level of signals.

Moduration noise on even the best machines tends to produce the result indicated in Fig.9 (b). The PCM system is, however, immune to modulation effects due to the mechanics of the tape system.

The dramatic difference between the distortion products introduced in the conventional recording process, and in the PCM system are indicated in Fig.10 and 11.

Fig.12 shows the difference in low frequency square wave characteristics between two systems.

4. PCM-1600, A PROFESSIONAL USE DIGITAL AUDIO UNIT [2]

4.1 Structure

Block diagram is similar to Fig. 5, but digital in/out put terminals are added, and A/D and D/A blocks are different. A/D and D/A converters are 16 bit linear and used for each channel separately.

Instead of CRC block in Fig.5, encoder and decoder blocks of " Cross Word Code " [7],[8] are added.

4.2 Dropout Compensation Method

A new error correcting code named " Cross Word Code " is developed especially for digital audio tape recorders [7],[8], and a type $C_1(12,6)$ is adopted in PCM-1600. Some parameters and features of $C_1(12,6)$ are listed up in Table 2. Burst error correctability of the code is 1.33 times longer than Reiger's bound [9].
This ability exceeding theoritical limitation is achieved at the expence of allowing the probability of miss correction at most 2^{-16} . The optimum code in the sense of real application is a little bit different from that in theory, but a balance is important between the probability of errors exceeding the correctability of the code, and the probability of miss correction when errors are within its correctability.

The code is effective both for burst and random errors. If errors exceed the correctability of the code, minimum numbers of words are renounced so that interpolation can be easily carried out. While in the case of conventional block code, the whole block must be renounced, or even miss correction is not protected at all.

Fig.13 shows the diagram of cross word code block, interleave block and data configuration on pseudo-video signals, where L and R are 16 bit data words of both channels and the subscript is data sequence, and C is 16 bit check word.

Table 2 Cross Word Code $C_1(12,6)$

*Block size 12 words

*Information words 6 words

*Check words 6 words

*Burst error correctability 4 words

*Random error correctability (full decode)

1 word error	100%
2 word error	100%
3 word error	46.8%
4 word error	15.8%
5 word error	7.6 %

*Check matrix

Information words. Check words

$$H = \begin{bmatrix} 110000 & 100000 \\ 001100 & 010000 \\ 000011 & 001000 \\ 101010 & 000100 \\ 010101 & 000010 \\ 000000 & 111001 \end{bmatrix}$$

By virture of interleave, burst errors within 2240 bits or 10.7 horizontal lines can be completely corrected in an interleave block, and burst errors within 4480 bits can be compensated by one word interpolation.

5. CONCLUSION

So far we have described a new PCM audio recording/reproduction system as an adapter of video tape recorders, which is the first digital audio recorder in the world ever produced in large quantity. This kind of configuration has the following advantages.

(1) The system is very economical. An adapter costs only $2000 and this will be greatly reduced within a few years. Any VTR including old fashioned black and white machines, can be used. One VTR is usable both for video and high-fi audio. This is economically attractive for consumers and for broadcasting companies.

(2) Various systems developed for VTR, can be used for digital audio systems. This includes editing machines, synchronized playback machines, remote control systems, and SMPTE coder/decoders. PCM recording or playback synchronized with video or another PCM system can be easily carried out.

(3) Existing transmission systems and distribution networks for video signals can be used for digital audio signals without any modifications.

(4) There is a possibility of PCM broadcasting over ordinary TV channels using existing facilities. No technical problems are expected.

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6. REFERENCES

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Fig. 1 PCM-1 and a VTR (Betamax)

Fig.2 PCM-1600 and a VTR (U-matic)

Dropout Length	Total nos. of dropout (1hr.x 6rolls)	Frequency
~ $\frac{1}{3}$H	29750	0.64295
$\frac{1}{3}$H ~ $\frac{2}{3}$H	13749	0.29714
$\frac{2}{3}$H ~ 1H	1913	0.04134
1H ~ $1\frac{1}{3}$H	532	0.01150
$1\frac{1}{3}$H ~ $1\frac{2}{3}$H	147	0.00318
$1\frac{2}{3}$H ~ 2H	59	0.00128
2H ~ $2\frac{1}{3}$H	31	0.00067
$2\frac{1}{3}$H ~ $2\frac{2}{3}$H	22	0.00048
$2\frac{2}{3}$H ~ 3H	15	0.00032
3H ~ $3\frac{1}{3}$H	11	0.00024
$3\frac{1}{3}$H ~ $3\frac{2}{3}$H	9	0.00019
$3\frac{2}{3}$H ~ 4H	3	0.00006
4H ~ $4\frac{1}{3}$H	7	0.00015
$4\frac{1}{3}$H ~ $4\frac{2}{3}$H	7	0.00015
$4\frac{2}{3}$H ~ 5H	3	0.00006
5H ~ $5\frac{1}{3}$H	1	0.00002
$5\frac{1}{3}$H ~ $5\frac{2}{3}$H	2	0.00004
$5\frac{2}{3}$H ~ 6H	4	0.00009
6H ~ $6\frac{1}{3}$H	3	0.00006
$6\frac{1}{3}$H ~ $6\frac{2}{3}$H		
$6\frac{2}{3}$H ~ 7H		
7H ~ $7\frac{1}{3}$H		
$7\frac{1}{3}$H ~ $7\frac{2}{3}$H	1	0.00002
$7\frac{2}{3}$H ~ 8H	1	0.00002
8H ~ $8\frac{1}{3}$H		
$8\frac{1}{3}$H ~ $8\frac{2}{3}$H		
$8\frac{2}{3}$H ~ 9H		
9H ~ $9\frac{1}{3}$H	1	0.00002
$9\frac{1}{3}$H ~ $9\frac{2}{3}$H		
$9\frac{2}{3}$H ~ 10H		

Fig.3 : Distribution of dropout

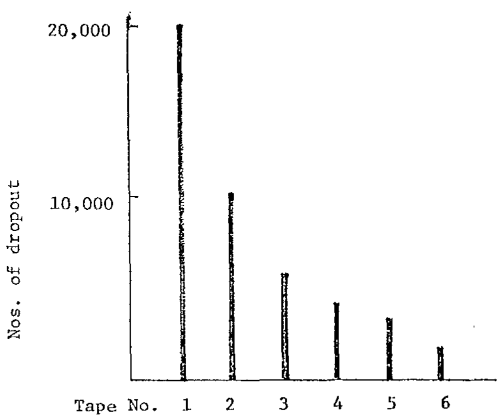


Fig. 4 : Difference in dropout due to tapes

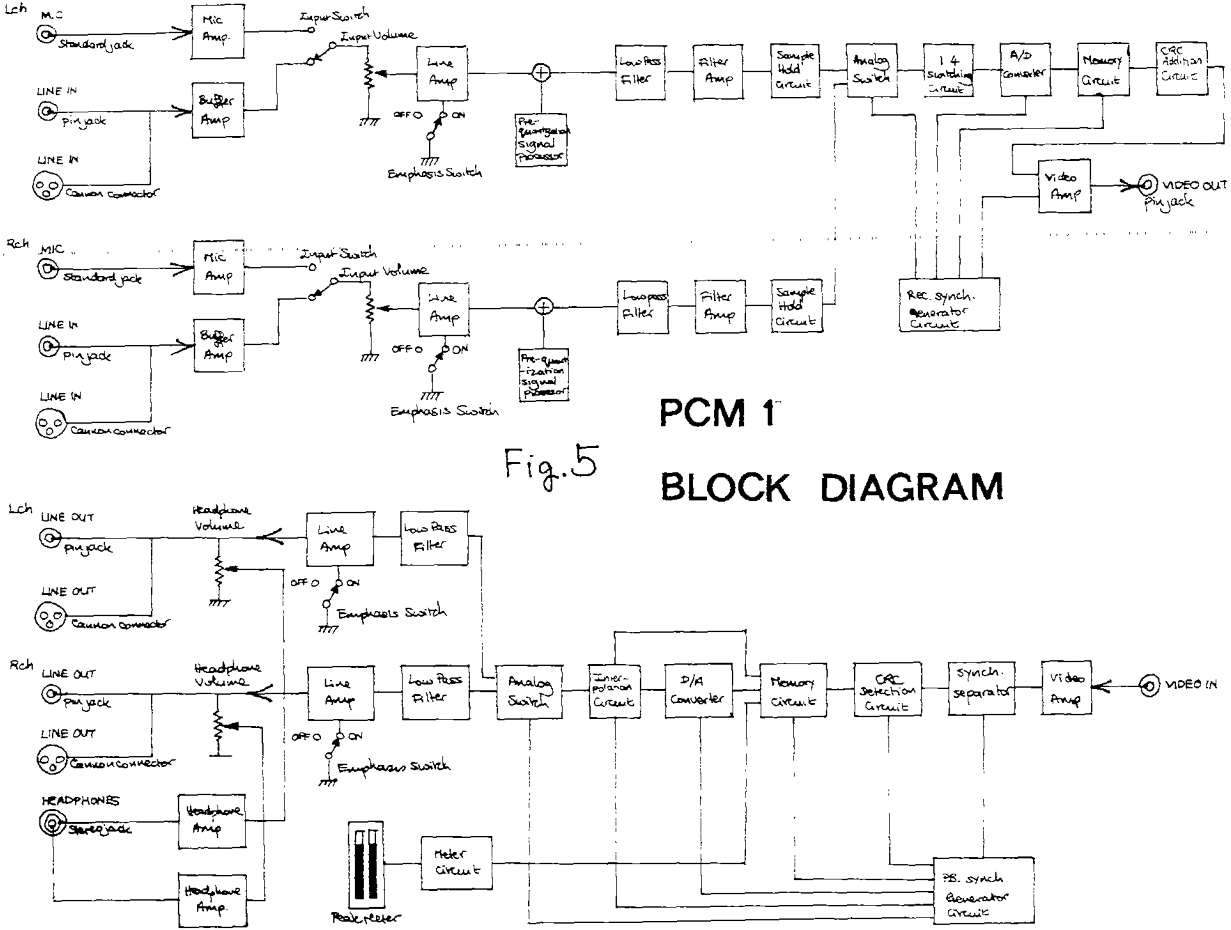


Fig.5

PCM 1

BLOCK DIAGRAM

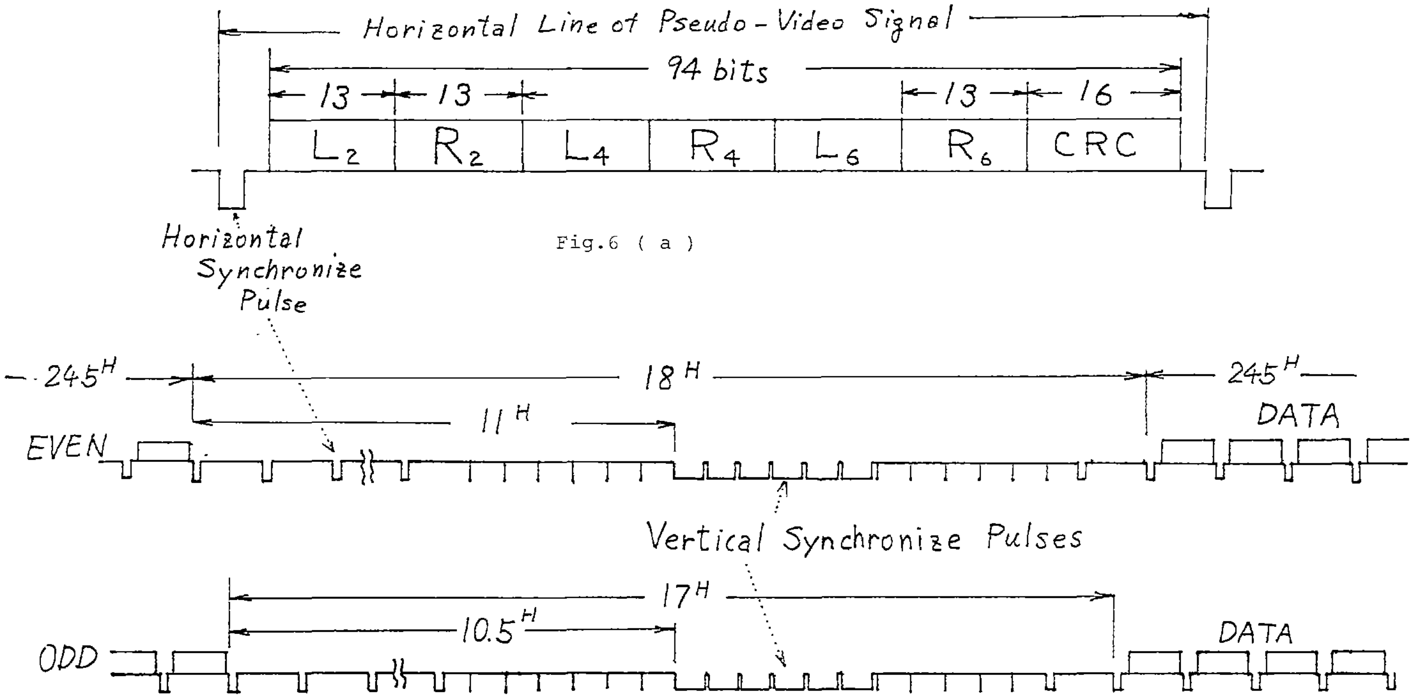


Fig.6 (a)

Fig.6 (b)

Fig.6 Data Configuration of PCM-1

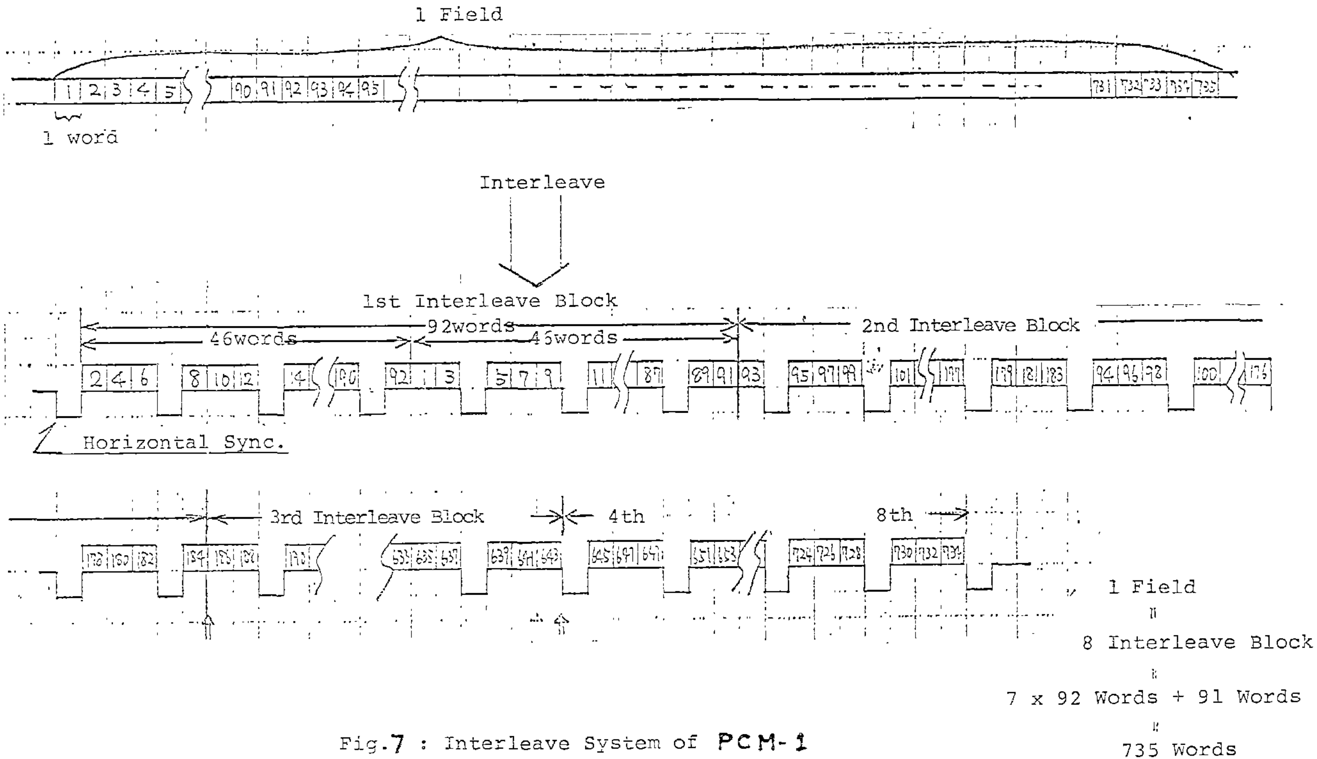
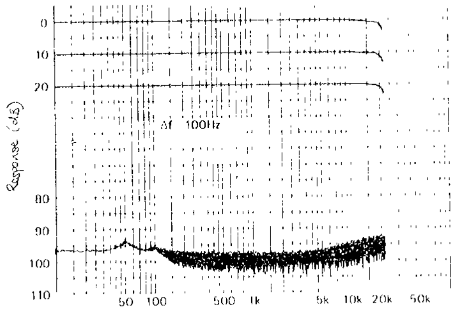


Fig.7 : Interleave System of PCM-1

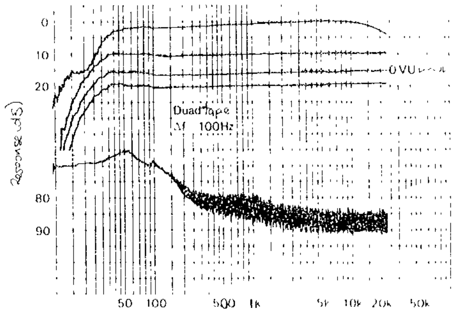
PCM-1



frequency

Fig.8(a)

2 track 15"/s tape deck

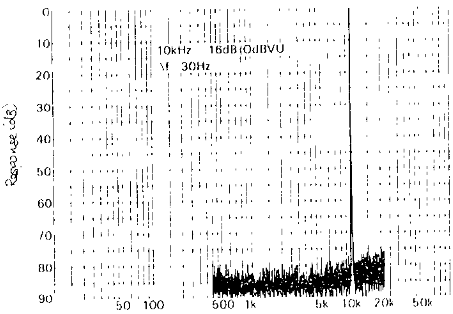


frequency

Fig.8(b)

Fig.8 Dynamic Range and Frequency Responce

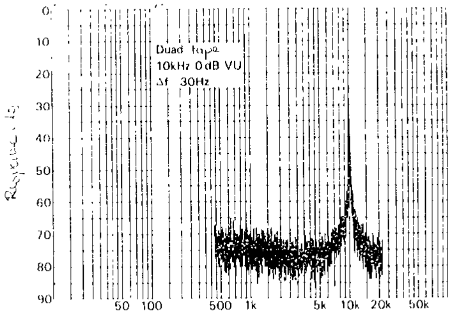
PCM-1



frequency

Fig.9(a)

2 track 15"/s tape deck



frequency

Fig.9(b)

Fig.9 Modulation Noise

PCM-1

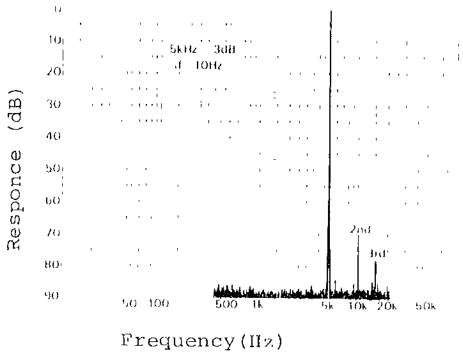


Fig.10(a)

2 track 15"/s tape deck

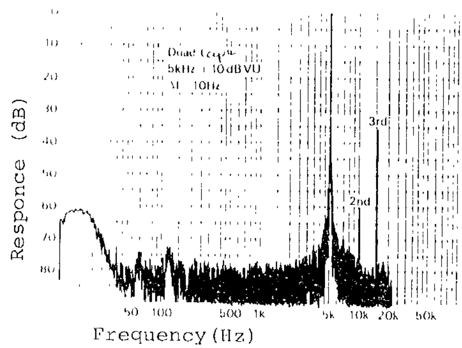


Fig.10(b)

Fig.10 Distortion (High Level)

PCM-1

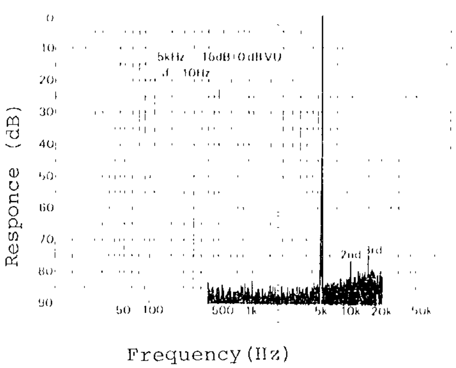


Fig.11(a)

2 track 15"/s tape deck

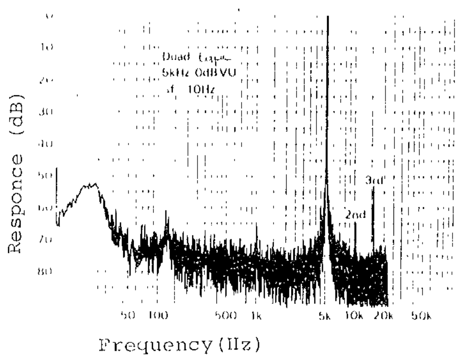


Fig.11(b)

Fig.11 Distortion (Low Level)

PCM-1

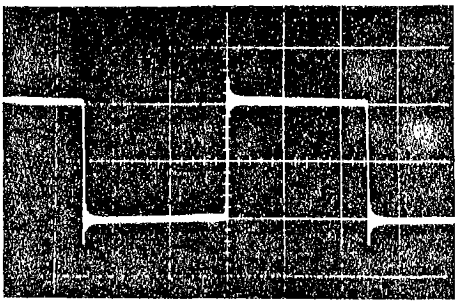


Fig.12(a)

2 track 15"/s tape deck

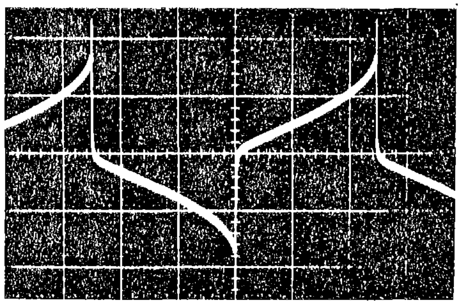
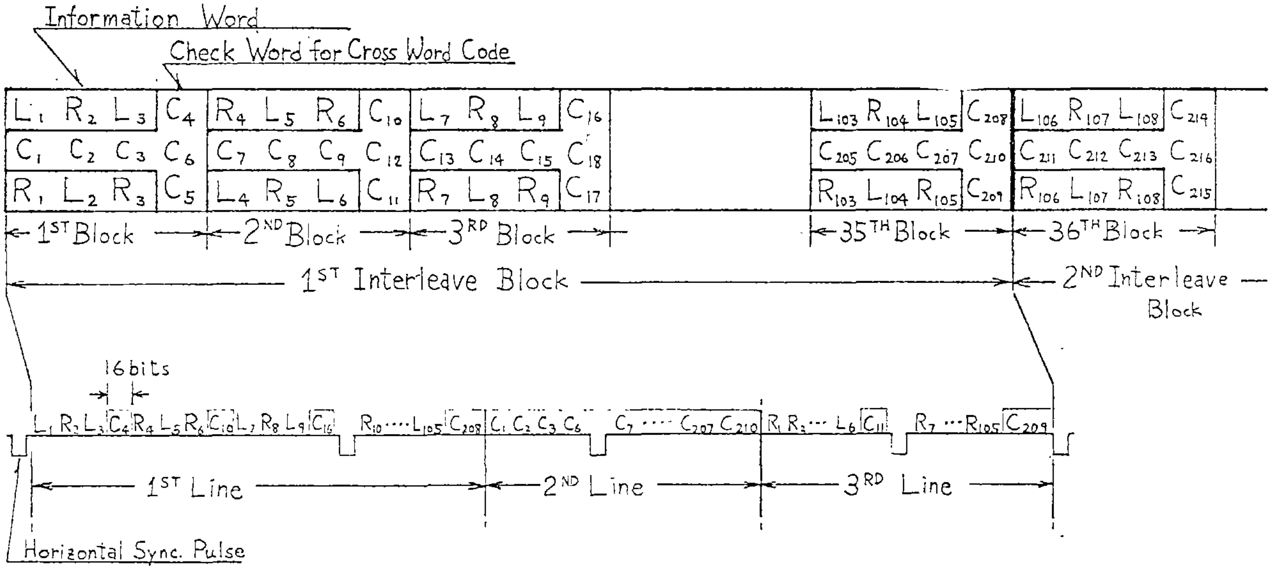


Fig.12(b)

Fig.12 Square Wave Responce (100 Hz)

Fig.13 Interleave System of PCM-1600



1 Video Field = 7 Interleave Block = 245 Block = 735 Information Word x 2 channel

1 Interleave Block = 35 Block = 105 Information Word x 2 channel